PHYSICS

Unit 3 & 4 – Written examination

2019 Trial Examination

<u>SOLUTIONS</u>

Section A – 1 mark each.

Question 1

Answer: **A**

Explanation:

Use $E = \dfrac{kQ}{x^2}$

$$x = \sqrt{\frac{kQ}{E}} = \sqrt{\frac{8.99\times10^9 \times 1.5\times10^{-6}}{50}} = 16.4 \text{ m}$$

Question 2

Answer: **A**

Explanation:

The fields from the two left-hand charges are equal and opposite so they cancel. Fields from the two right-hand charges have equal magnitudes (as they are the same distance from P) but the field from the positive charge is repulsive, so is up and to the left, while the field from the negative charge is attractive, so up and to the right. The horizontal components of these two fields will cancel out so the resultant field will be up.

Question 3

Answer: **B**

Explanation:

$$F_1 = \frac{GM_1M_2}{x^2}$$

$$F_2 = \frac{G\times 3M_1M_2}{(2x)^2} = \frac{3GM_1M_2}{4x^2} = \frac{3F_1}{4} = \frac{3\times120}{4} = 90 \text{ N}$$

Question 4

Answer: **C**

Explanation:
If a **positive** charge is deflected east then using the right-hand palm rule the magnetic field must be north and the velocity into the page or the magnetic field must be out of the page and the velocity north.
A **negative** charge will be deflected in the same direction if it is travelling in the opposite direction to the positive charge. In this case the directions would be magnetic field north and velocity out of the page or magnetic field out of the page and velocity south. Only the first of these matches one of the alternatives, C.

Question 5

Answer: **C**

Explanation:
Energy used is given by the area under the graph.
Estimate by counting rectangles each of which represents $2 \times 1 = 2$ J
24 rectangles $\times 2 = 48$ J

Question 6

Answer: **D**

Explanation:
The frequency of the emf output has doubled so the rate of rotation must have been doubled. But this should also double the peak emf to 40 V. However the peak emf on the second graph is only 30 V which means some other change must have taken place, such as a decrease in the magnitude of the magnetic field.

Question 7

Answer: **D**

Explanation:
Reducing resistance will reduce power loss but raising the wires will not decrease resistance. Reducing the current by increasing the voltage will also reduce power loss but this must be done at the generator end so the current through the transmission wires is reduced.

Question 8

Answer: **A**

Explanation:
The emf is the dependent variable and the area of the loop and the rate of rotation are the controlled variables.

Question 9

Answer: **C**

Explanation:
Ricardo's apparent weight is equal to the normal reaction force of the lift floor acting on him. The acceleration of the lift is upwards so his apparent weight is given by:

$$N = mg + ma = m(g + a)$$

$$m = \frac{N}{g + a} = \frac{836}{9.8 + 1.5} \approx 74 \text{ kg}$$

Question 10

Answer: **A**

Explanation:
Both **B** and **D** are true of Einstein but are not how he resolved the contradiction. **C** is false as Einstein proposed that events are **not** necessarily simultaneous for all observers.

Question 11

Answer: **D**

Explanation:
The time taken in the muons' frame of reference is the proper time and will not change but the time in the scientists' frame of reference will be dilated.
The distance in the scientists' stationary frame of reference is the proper distance and will not change but the distance travelled in the muons' frame of reference will be contracted.

Question 12

Answer: **B**

Explanation:
Change of momentum = impulse on ball.

$$m\Delta v = F\Delta t$$

$$\Delta v = \frac{F\Delta t}{m} = \frac{3150 \times 0.0037}{0.150} = 77.7 \text{ m s}^{-1}$$

$$\Delta v = v_f - v_i$$

$$v_f = v_i + \Delta v$$

Taking the initial direction of the ball as positive.

$$v_f = 27 - 78 = -51 \text{ m s}^{-1}$$

Hence the final speed is 51 m s^{-1}

Question 13

Answer: **B**

Explanation:
The wavelength of the wave is 8 m.

$$f = \frac{v}{\lambda} = \frac{10}{8} = 1.25 \text{ Hz}$$

Question 14

Answer: **D**

Explanation:
Bright band separation $\Delta x = \frac{\lambda L}{d}$

$$d = \frac{\lambda L}{\Delta x} = \frac{600\times10^{-9}\times3}{5\times10^{-3}} = 3.6\times10^{-4}\ \text{m} = 0.36 \text{ mm}$$

Question 15

Answer: **A**

Explanation:
The spacing of the diffraction bands is proportional to the de Broglie wavelength of the electrons so the wavelength must have decreased.

Now $\lambda = \frac{h}{mv}$, so a decrease in wavelength will be caused by an increase in speed.

Question 16

Answer: **D**

Explanation:
Red light has a longer wavelength than blue light and is not refracted as strongly so either C or D. But it will not come out of this prism parallel to the blue light. so not C.

Question 17

Answer: **C**

Explanation:
Ultraviolet radiation is shorter than violet light and therefore less than 400 nm (4.0×10^{-7} m) but only down to about 10 nm (1.0×10^{-9} m).

Question 18

Answer: **D**

Explanation:
If the magnitude of the stopping voltage is decreased this means that the maximum kinetic energy of the photelectrons has decreased. This is proportional to the frequency, so the light frequency must have decreased and thus the wavelength must have increased.
The photoelectric current increases when the light intensity increases.

Question 19

Answer: **C**

Explanation:
An absorption spectrum is formed from the full spectrum of light when certain wavelengths of light are absorbed by atoms or molecules of a gas, when their electrons jump to higher energy levels, which result in dark lines in the spectrum at those wavelengths.

Question 20

Answer: **D**

Explanation:
A is an incandescent light globe, B the basis of synchrotron radiation and C the principle of laser light.

Section B

Question 1

a. P is negative and Q is positive.
Electric field lines point away from a positive and toward a negative charge.

3 marks

b. Gravitational field lines always point to a mass so they could not come out of Q as shown in Figure 1.

2 marks

Question 2

a. Positive (using the right-hand palm rule).

1 mark

b. $r = \dfrac{mv}{qB}$

$$m = \frac{qBr}{v} = \frac{3.2\times10^{-19}\times0.025\times0.125}{1.5\times10^{5}} = 6.7\times10^{-27}\ \text{kg}$$

2 marks

c. R is being accelerated because the direction of its velocity is changing. When charged particles are accelerated they emit electromagnetic radiation.

2 marks

Question 3

a. $g = \dfrac{GM}{r^2}$

$$r = \sqrt{\frac{GM}{g}} = \sqrt{\frac{6.67\times10^{-11}\times6.7\times10^{20}}{0.25}} = 4.2\times10^{5}\ \text{m}$$

3 marks

b. $F = \dfrac{GM_1M_2}{r^2}$

$$F = \frac{6.67\times10^{-11}\times6.7\times10^{20}\times0.7}{\left(2.6\times10^{7}\right)^2} = 4.6\times10^{-5}\ \text{N}$$

3 marks

Question 4

a. $F = ma$

$F = 3.12 \times 10^{23} \times 0.551 = 1.72 \times 10^{23}$ N

1 mark

b. 1.72×10^{23} N

The force of the planet on the star is the same as the force of the star on the planet.

1 mark

c. $a = \dfrac{4\pi^2 r}{T^2}$

$$T = \sqrt{\frac{4\pi^2 r}{a}} = \sqrt{\frac{4\pi^2 \times 7.56 \times 10^{10}}{0.551}} = 2.327 \times 10^6 \text{ s}$$

$$T = \frac{2.327 \times 10^6}{24 \times 60 \times 60} = 27 \text{ days}$$

3 marks

d. $F_Y = \dfrac{GM_s M_Y}{{r_Y}^2}$ where M_s is the mass of the star.

$$F_Z = \frac{GM_s M_Z}{{r_Z}^2}$$

$$\frac{F_Y}{F_Z} = \frac{M_Y}{M_Z} \times \left(\frac{r_Z}{r_Y}\right)^2 = \frac{1}{20} \times \left(\frac{12}{1}\right)^2$$

$$\frac{F_Y}{F_Z} = 7.2$$

3 marks

Question 5

a. Direction is up the page.

$F = BIl$

$$l = \frac{F}{BI} = \frac{0.18}{0.25 \times 1.8} = 0.4 \text{ m}$$

3 marks

b. The direction of the current is now parallel to the magnetic field which means there is no component of the magnetic field perpendicular to the current. No perpendicular component means no force will be induced.

2 marks

Question 6

a. $\phi = BA = B\pi r^2$

$$r = \sqrt{\frac{\phi}{\pi B}} = \sqrt{\frac{0.18}{\pi \times 0.73}} = 0.28 \text{ m}$$

2 marks

b. $\varepsilon = \dfrac{N\Delta\phi}{\Delta t}$

$\Delta t = \dfrac{N\Delta\phi}{\varepsilon} = \dfrac{20 \times 0.18}{72} = 0.05 \text{ s}$ for a quarter of a turn

Period for one turn $T = 4 \times 0.05 = 0.2 \text{ s}$

$f = \dfrac{1}{T} = \dfrac{1}{0.2} = 5 \text{ Hz}$

3 marks

c. Positive.
The external magnetic flux from right to left through the coil is **decreasing**. According to Lenz's Law the induced flux in the coil opposes this change and must therefore be from right to left. This requires a current from A to B which means A must be positive.

3 marks

d. Maximum emf is produced when the coil is horizontal because the rate of change of the flux is a maximum at this orientation.

2 marks

e. The slip rings will provide a variable emf that alternates between positive and negative values.
The commutator output will also vary but it will not change polarity.

2 marks

Question 7

a. $V_{RMS} = \dfrac{V_{peak\ to\ peak}}{2\sqrt{2}} = \dfrac{6788}{2\sqrt{2}} = 2400 \text{ V}$

$I_{RMS} = \dfrac{P_{RMS}}{V_{RMS}} = \dfrac{2.88 \times 10^6}{2400} = 1200 \text{ A}$

2 marks

b. $\dfrac{N_2}{N_1} = \dfrac{I_1}{I_2}$

$N_2 = \dfrac{N_1 I_1}{I_2} = \dfrac{60 \times 1200}{240} = 300 \text{ turns}$

2 marks

c. Maximum $P_{loss} = 0.06 \times 2.88 \times 10^6 = 1.728 \times 10^5$ W

$P_{loss} = I^2 R$

$R = \dfrac{P_{loss}}{I^2} = \dfrac{1.728 \times 10^5}{240^2} = 3\ \Omega$

2 marks

Question 8

a. $\gamma = \dfrac{1}{\sqrt{1 - \left(\dfrac{v}{c}\right)^2}} = \dfrac{1}{\sqrt{1 - (0.76)^2}} = 1.54$

1 mark

b. $L = \dfrac{L_0}{\gamma}$ but the length of the spaceship at rest is its proper length, L_0.

$L_0 = L\gamma = 140 \times 2.5 = 350$ m

2 marks

c. $E_K = (\gamma - 1)mc^2$

$m = \dfrac{E_K}{(\gamma - 1)c^2} = \dfrac{6.75 \times 10^{24}}{(2.5 - 1)(3 \times 10^8)^2} = 5.0 \times 10^7$ kg

2 marks

Question 9

a. Between the lowest position and highest positions of the block:

$\Delta E_g = mg\Delta h$

$m = \dfrac{\Delta E_g}{g\Delta h} = \dfrac{24.5}{9.8 \times 0.500} = 5.0$ kg

2 marks

b. Between the lowest and highest positions of the block:

$\Delta E_g = \Delta E_s = \dfrac{1}{2}k(\Delta x)^2$

$k = \dfrac{2\Delta E_g}{(\Delta x)^2} = \dfrac{2 \times 24.5}{0.500^2} = 196$ N m^{-1}

2 marks

c. The total energy of the block will be 24.5 J at any point in its motion.
The velocity will be a maximum when the acceleration is zero hence the maximum kinetic energy occurs at the midpoint of the motion when $\Delta x = 25.0$ cm

Maximum $E_k = 24.5 - E_g - E_s = 24.5 - mg\Delta h - \frac{1}{2}k\left(\Delta x\right)^2$

Maximum $E_k = 24.5 - 5.0 \times 9.8 \times 0.25 - 0.5 \times 196 \times 0.250^2 = 6.125$ J

$\frac{6.125}{24.5} \times 100 = 25\%$

3 marks

Question 10

Nadi's blood, being a fluid, tends to continue along a tangent to the path Nadi follows. However, Nadi's body is constantly being accelerated towards the centre of the circular arc and hence away from the path his blood is tending to follow. So, his body (and hence his head) is being pulled away from his blood.

2 marks

Question 11

a. N-S axis or the Up-Down axis as transverse waves oscillate along an axis perpendicular to the direction of motion of the wave.

2 marks

b. E-W axis as longitudinal waves oscillate along the direction of motion of the wave.

2 marks

Question 12

a. Resonance on the string will be produced by an external frequency that matches one of the natural frequencies of vibration of the string.

Frequency, $f = \frac{v}{\lambda}$

For a string fixed at both ends the lowest or fundamental natural frequency, f_1, occurs when the wavelength is twice the length of the string, L.

So $f_1 = \frac{v}{2L} = \frac{456}{2 \times 0.30} = 760$ Hz

3 marks

b. For a string fixed at both ends the next highest natural frequency occurs at twice the fundamental frequency.
Hence $f_2 = 2f_1 = 2 \times 760 = 1520$ Hz
The string will also resonate at 1520 Hz.

2 marks

Question 13

The first light used has a wavelength of $\lambda_1 = \dfrac{3\times10^8}{3.3\times10^{15}} = 9.1\times10^{-8}$ m

The ratio of this wavelength to the slit width is $\dfrac{9.1\times10^{-8}}{270\times10^{-9}} \approx 0.34$

For the second light, $\lambda_2 = \dfrac{3\times10^8}{1.2\times10^{15}} = 2.5\times10^{-7}$ m

and the wavelength to slit width is $\dfrac{2.5\times10^{-7}}{270\times10^{-9}} \approx 0.93$

Maximum diffraction occurs when the wavelength to slit width ratio is closest to 1 so the second light used will diffract more significantly.

4 marks

Question 14

The X-rays will have the same momentum as the charged particles.

$$\lambda = \frac{h}{p} = \frac{6.63\times10^{-34}}{1.66\times10^{-23}} = 3.99\times10^{-11} \text{ m}$$

$$f = \frac{c}{\lambda} = \frac{3\times10^8}{3.99\times10^{-11}} = 7.5\times10^{18} \text{ Hz}$$

2 marks

Question 15

a. For bright lines path difference $= n\lambda$
A is the 4th bright line from the centre so $n = 4$
Path difference $= 4\times430 = 1720$ nm

3 marks

b. Increasing the wavelength would have increased the distance between the bright bands. To decrease the separation of the bands back to the original value the slit separation would have to be decreased by the same proportion as the wavelength was increased.

2 marks

c. Point P will be on the 3rd dark band from the centre.

For dark bands, path difference $= \left(n - \dfrac{1}{2}\right)\lambda$

$$\lambda = \frac{\text{Path difference}}{n - \frac{1}{2}} = \frac{1.275\times10^{-6}}{3 - \frac{1}{2}} = 5.1\times10^{-7} \text{ m}$$

$\lambda = 510$ nm

3 marks

Question 16

a. $\frac{n_2}{n_1} = \frac{\sin\theta_1}{\sin\theta_2}$

$$n_2 = \frac{n_1 \sin\theta_1}{\sin\theta_2} = \frac{1.81\sin 35°}{\sin 51.3°} = 1.33$$

2 marks

b. $\frac{\sin\theta_c}{\sin 90°} = \frac{n_2}{n_1}$

$$\theta_c = \sin^{-1}\left(\frac{n_2}{n_1}\right) = \sin^{-1}\left(\frac{1.33}{1.81}\right) = 47.3°$$

2 marks

Question 17

a. The uncertainty in reading the voltmeter is half of the difference between the smallest scale markings so:
Uncertainty in voltage readings $= \pm 0.5 \times 0.2 = \pm 0.1$ V.
This means that the uncertainty in the maximum kinetic energies in eV will be ± 0.1 eV and the uncertainty of the maximum kinetic energies in J would be $\pm 1.6 \times 10^{-20}$ J
For the 9.00×10^{14} Hz data point the kinetic energy value in J is:
$1.73 \times 1.6 \times 10^{-19} = 2.77 \times 10^{-19}$ J
Lower extreme of kinetic energy error bars $= 2.77 \times 10^{-19} - 1.6 \times 10^{-20} = 2.61 \times 10^{-19}$ J
Upper extreme of kinetic energy error bars $= 2.77 \times 10^{-19} + 1.6 \times 10^{-20} = 2.93 \times 10^{-19}$ J

6 marks

b. Draw a line of best fit to the plotted data points and extend it back to the left.
The point at which this line intercepts the frequency axis will give the threshold frequency.
The point at which this line intercepts the energy axis will give the magnitude of the work function.

3 marks

Question 18

a. In the wave model the energy was related to the intensity of the light and not the frequency; so more intense light should transfer more energy to the photoelectrons and the light frequency should have no effect on the energy of photoelectrons.

2 marks

b. Einstein proposed that light consisted of particles, or photons, each of which had an energy that depended on the light frequency ($E = hf$). This meant that higher frequency photons could transfer more energy when they interacted with an electron and produce higher energy photoelectrons.
Einstein also proposed that the intensity of the light was related to the number of photons arriving in a given time, so higher intensity light would release more photoelectrons in a given time but not affect their energy.

4 marks

Question 19

a. $E = \dfrac{hc}{\gamma}$

$$E_1 = \frac{4.14\times10^{-15}\times3\times10^{8}}{185.4\times10^{-9}} = 6.7 \text{ eV}$$

$$E_2 = \frac{4.14\times10^{-15}\times3\times10^{8}}{496.8\times10^{-9}} = 2.5 \text{ eV}$$

2 marks

b. <u>Sodium</u>
6.7 eV is greater than even the largest energy level gap of 5.1 eV. There are energy gaps of 2.1 eV between 0 and 2.1 eV and 3.0 between 2.1 and 5.1 eV but no gaps of 2.5 eV so there is no evidence that sodium is present.
<u>Mercury</u>
The difference between -10.4 and -3.7 is 6.7 eV so the 185.4 nm absorption line is evidence that mercury is present.
<u>Hydrogen</u>
The difference between -3.4 and -0.9 is 2.5 eV so the 496.8 nm absorption line is evidence that hydrogen is present.
There is evidence that two of the elements are present so Alyssa is correct.

5 marks